MASTER IN CIVIL ENGINEERING
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WATER PERMEABILITY AND CARBONATION ON FOAMED CONCRETE

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Especially dedicated to my love Nurdita, Sofea & Sorfina, Abah (Hj.Sulaiman), Mak (Hjh. Khadijah), Ayah Tok, Mak Tok, Families, Brothers and Sisters

My love to you all will remain forever…

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ABSTRACT

Foamed concrete is a controlled density low strength material with density ranging from 300 kg/m^3 to 1800 kg/m^3 suitable for construction of walls. The acceptance of foamed concrete blocks and panels by the Construction Industry Development Board of Malaysia as components of industrialized building system has promoted its commercial applications. It is made of cement, fine sand, water and preformed foam. Its self-compacting properties have enhanced productivity for mass production. Previous studies revealed findings on the use of large volume partial cement replacement materials without adverse effect on its physical and mechanical properties. This study focused mainly on the effect of the density of foamed concrete on carbonation and water permeability. The ability to vary the density of foamed concrete is considered a unique characteristic compared with normal concrete. Carbonation is usually considered as a negative impact on reinforced concrete. It is the process of pH reduction of concrete from 12.6 to 9.0 in the presence of carbon dioxide and moisture. The reduction of alkalinity means the loss of protection against corrosion to steel bars embedded within concrete. However, for non-structural applications of foamed concrete in wall construction without steel bars or with the use of corrosion inhibitor, carbonation is turned into an advantage for sustainable construction. The ability of foamed concrete to speed up the absorption of carbon dioxide is an important aspect to be explored for its potential use in reducing carbon footprint from the construction industry. The objective of this study is to explore a relationship between carbonation depth, water permeability and the density of foamed concrete. The laboratory tests were conducted on concrete cubes and prisms for up to one and a half years. The water permeability method was developed based on ISO/DIS 7031. The test results indicate that increasing density of foamed concrete tends to reduce its water permeability and carbonation depth.

The plot of carbonation depth against permeability coefficient produces a linear relationship. The rate of carbonation was found to be inversely proportional to the square root of density. An empirical formula incorporating density as a variable based Currie’s formula is produced. This finding is expected to excite researchers who are concerned with the use of concrete for sustainable construction. Its tendency to absorb carbon dioxide faster than normal concrete from the atmosphere in the carbonation process is expected to lead to widespread use of foamed concrete for environmental and economical advantages.

ABSTRAK

Konkrit berbusa adalah material berketumpatan terkawal dan berkekuatan rendah dengan ketumpatan daripada 300 kg/m^3 hingga 1800 kg/m^3 sesuai untuk pembinaan dinding. Penerimaan blok dan panel konkrit berbusa oleh Lembaga Pembangunan Industri Pembinaan Malaysia sebagai komponen sistem bangunan berindustri telah mempromosikan nilai-nilai komersialnya. Ia diperbuat daripada simen, pasir halus, air and busa. Keupayaannya yang tidak memerlukan pemadatan telah menggalakkan pengeluarannya secara besar-besaran. Kajian-kajian terdahulu telah menunjukkan penemuan-penemuan ke atas penggunaan sebahagian besar bahan pengganti material simen tanpa kesan berlawanan terhadap ciri-ciri fizikal dan mekanikalnya. Fokus utama kajian ini adalah terhadap kesan ketumpatan konkrit berbusa ke atas kadar pengkarbonatan dan kebolehtelapan air. Kebolehan untuk mengubah ketumpatan konkrit berbusa dianggap satu sifat yang unik berbanding konkrit biasa. Pengkarbonatan biasanya dianggap satu kesan negatif ke atas konkrit bertetulang. Pengkarbonatan adalah proses pengurangan pH konkrit daripada 12.6 ke 9.0 dengan kehadiran karbon dioksida dan wap air. Pengurangan sifat alkali bermakna kehilangan perlindungan terhadap pengaratan tetulang besi di dalam konkrit. Walaubagaimanapun, untuk penggunaan bukan struktur konkrit berbusa dalam pembinaan dinding tanpa tetulang besi atau dengan penggunaan penghalang karat, pengkarbonatan menjadi satu kelebihan untuk pembinaan lestari. Keupayaan konkrit berbusa untuk mempercepatkan kadar penyerapan karbon dioksida adalah satu aspek penting yang perlu dikaji potensinya di dalam usaha untuk mengurangkan kadar pelepasan karbon daripada industri pembinaan. Objektif utama kajian ini adalah untuk meneroka hubungan di antara kadar pengkarbonatan, kebolehtelapan air dan ketumpatan konkrit berbusa. Ujian makmal dilakukan ke atas kiub-kiub dan prisma-prisma konkrit berusia sehingga satu setengah tahun. Kaedah ujian

kebolehtelapan air adalah dibangunkan berdasarkan ISO/DIS 7031. Keputusan ujian yang diperolehi menunjukkan peningkatan ketumpatan konkrit berbusa akan mengurangkan kebolehtelapan air dan kadar pengkarbonatan. Plotan kadar pengkarbonatan terhadap pekali kebolehtelapan menghasilkan satu garisan lurus. Kadar pengkarbonatan didapati berkadar sonsang dengan punca kuasa dua ketumpatan. Satu formula empirik yang menggabungkan ketumpatan sebagai pengubah berdasarkan formula Currie telah dihasilkan. Penemuan ini dijangkakan akan menyemarakkan semangat penyelidik-penyelidik yang berminat dengan penggunaan konkrit untuk pembinaan lestari. Keupayaannya untuk menyerap gas karbón dioksida lebih pantas berbanding konkrit biasa daripada atmosfera di dalam proses pengkarbonatan dijangka akan membuka ruang terhadap penggunaan konkrit berbusa untuk faedah alam sekitar dan ekonomi.

TABLE OF CONTENTS

2. LITERATURE REVIEW

3. METHODOLOGY

4. DATA ANALYSIS AND DISCUSSION

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND SYMBOLS

ACI	-	American Concrete Institute
ASTM	-	American Society for Testing and Materials
BS	-	British Standard
DOE	-	Department of Environmental
MS	-	Malaysia Standard
OPC	-	Ordinary Portland Cement
C_2S	-	Dicalcium Silicate
C_3S	-	Tricalcium Silicate
CH	-	Calcium Hydroxide
C-S-H	-	Calcium Silicate Hydrate
TIA	-	Timber Industrial Ash
Mpa	-	Mega Pascal
^0C	-	Degree Celcius
CO_2	-	Carbon Dioxide
$CaCO_3$	-	Calcium Carbonate
RH	-	Relative Humidity
SAA	-	Surface Active Agents
AAC	-	Autoclaved Aerated Concrete

LIST OF APPENDICES

CHAPTER I

INTRODUCTION

1.1 GENERAL

Concrete is a composite material which consists essentially of cement, aggregates, water and admixtures in certain proportion. It is an important and widely used construction material. The self-weight of normal weight concrete represents a very large proportion of the total load on the structure.

Based on density of concrete, it can be classified into three major categories. The density of heavy weight concrete is more than 3600 kg/m^3 and normal weight concrete is about 2400 kg/m^3. Neville, A.M, (1995) classifies lightweight concrete is one with density of 2000 kg/m^3 or less. The practical range of densities of lightweight concrete is between 300 kg/m^3 and 1800 kg/m^3.

Lightweight concrete has unique benefits in construction to increase productivity. The use of lightweight concrete will reduce the self-weight of the concrete structures (Short, A. et al., 1978). Besides that, lightweight concrete also gives better thermal insulation compared with the normal weight concrete.

Lightweight concrete can be divided into three types namely lightweight aggregate concrete, no fines concrete and aerated concrete (Neville, A.M. and Brooks., J.J., 1987). Lightweight concrete has traditionally been made using manufactured aggregates such as expanded shale, clay, vermiculite, pumice and scoria. However, the study conducted by August, J. (1997) noted that the very lightest mixes (densities from 300 to 900 kg/m^3) contain air voids in the absence of aggregates and in Europe it is referred to as cellular or aerated concrete. Cellular concrete is also known as Autoclaved Aerated Concrete (AAC) in some countries because of the way the aerated concrete is cured.

Foamed concrete which is also known as aerated concrete and cellular concrete was first developed in Scandinavia some thirty years ago (Neville, A.M, 1995). It is one of the lightweight product produced by adding a foaming agent (usually some form of hydrolyzed protein or resin soap) to the mortar during mixing. The agent introduces and stabilizes air bubble during mixing at high speed. In some process, stable pre-formed foam is added to the mortar during mixing to produce foamed concrete.

Nowadays, foamed concrete has been widely used in construction industry especially for building walls. Foamed concrete technology is relatively new in Malaysia even though it has been used long time ago in Europe and USA. By using this type of technology in concrete construction, many benefits can be obtained like reduction in member sizes, provide better thermal insulation, savings in cost, enables much faster pace of building construction and reduce the carbon footprint from the industries by absorbing CO_2. The production of foamed concrete on a small scale is a fairly easy process which does not involve any expensive or heavy machinery and in most cases uses equipment that is already available for normal concrete production. A construction research with precast block and cast in situ foamed concrete wall system is branded as KUiK Wall. The concrete density varies between 1000 kg/m^3 and 1500 kg/m^3. Precast block is designed to be of lower density around 1000 kg/m^3. Higher density cast in situ wall is designed to achieve higher compressive strength.

Permeability is the ability to transport different fluids or gases, such as water, chlorides, sulfates, oxygen and carbon dioxide. They can move through the concrete in different ways, but all transport depends primarily on the structure of the hydrated cement paste. Actually, permeability refers to flow through a pore medium. But the fluids can also penetrate through concrete by diffusion and sorption (Neville, A.M, 1995). The two parameters involved in this study are water permeability and carbonation depth penetration.

1.2 AIM AND OBJECTIVES OF STUDY

The aim of this study is to find the relationship between water permeability, carbonation depth and density of foamed concrete. The purpose is to predict carbonation depth and water permeability based on foamed concrete density. The information will provide useful reference for the contractors to use foamed concrete in the construction industry towards carbon neutral development in Malaysia.

The objectives of this research are:

i. To determine the water permeability and carbonation depth of foamed concrete.

ii. To develop a relationship between water permeability, carbonation depth and density of foamed concrete.

1.3 PROBLEM STATEMENT

Foamed concrete is a well-established material in building, void filling and highway reinstatement uses in European countries. In Malaysia, it has a potential in environmental sustainability by reducing the carbon footprint from industries. The foamed concrete can reduce the carbon footprint from the concrete industry by absorbing CO_2 from the environment. Concrete's carbon footprint is fairly large due to the energy used to heat limestone ($CaCO_3$) in kilns to form CaO, one of major components in concrete and the large quantities of CO_2 released as the conversion of limestone to CaO proceeds. By using foamed concrete, the carbon footprint can be reduced for environmental sustainability.

Foamed concrete can be used as non structural components in building and precast product especially for Industrialized Building System (IBS). Since water permeability and carbonation depth are closely related to density, therefore this study has been focusing on these two parameters. The lack of information and study on the effect of water permeability and carbonation on foamed concrete makes the findings relevant for specifying the foamed concrete with respect to density.

1.4 SCOPE OF WORK

The scope of this research was to study the effects of water permeability and carbonation on foamed concrete. This research was also to develop a relationship between water permeability, carbonation depth and density of foamed concrete. The scopes can be summarized as:

i. Experimental study on water permeability and carbonation of foamed concrete with densities from 1300 kg/m^3 to 1800 kg/m^3.

ii. Analytical study on the relationship between water permeability, carbonation depth and density of foamed concrete.

1.5 HYPOTHESIS

The hypothesis of this study is the foamed concrete has high water permeability and a high carbonation depth. Carbonation is related to CO_2 uptake from the atmosphere which adds value to foamed concrete applications towards sustainable development.

1.6 THE RESEARCH LIMITATIONS

This research is limited to the study of foamed concrete densities ranging from 1300 to 1800 kg/m^3. The maximum time period for carbonation test was 1.5 years. The curing methods used were air curing and moist curing based on British Standard Institution 1881: Part 111:1983. The foamed concrete was exposed in laboratory condition and also in natural environment condition which was exposed to rain and sun outside the laboratory. The water permeability value was determined using Germann Water Permeability Test GWT ISO/DIS 7031 based on Danish Standard. The carbonation depth was determined using phenolphthalein indicator and based on British Standard Institution 1881: Part 201:1986. The compressive strength was using Compressive Strength Test Machine and based on British Standard Institution 1881: Part 116:1983. Water absorption was determined as a percentage of the dry weight and was based on British Standard Institution 1881:Part 122:1983.

1.7 SIGNIFICANCE OF RESEARCH

The main purpose of this study is to find the relationship between water permeability, carbonation depth and density of foamed concrete. If the relationship can be established, then the carbonation depth and water permeability can be specified based on foamed concrete density. This information is very useful for the designing of non structural applications with a good absorbing parameter to neutralize carbon emissions. This will contributed for the realization of Green Building Concept in our country and reduce the carbon footprint. The information will be a very useful reference to the industry's players towards building greener properties.

The relationship between water permeability, carbonation depth and density of foamed concrete can also be a part in creating sustainability indicators. The sustainability indicators are the instruments for measuring the changes in the quality and state of sustainability of any system. It is a tool to measure and calibrate progress towards sustainable construction. The indicator can provide an early warning to prevent environmental damage from the development. It will set a milestone for projects towards environmental sustainability. The indicator can provide crucial guidance for decision making in variety of ways. Without indicators, the status, trends and long term changes can not be measure. The foamed concrete is a part of sustainable construction because it can reduce carbon emissions. Therefore, the water permeability, carbonation depth and density of foamed concrete can become sustainability indicators.

1.8 LAYOUT OF THESIS

The layout of the thesis are :

- Chapter I provides the introduction, aim and objectives of study, problem statement, scope of work, hypothesis, limitation of research, significance of research and layout of thesis.

- Chapter II examines initially the existing body of knowledge on the subject. This chapter comprises fourteen sub-chapters which are introduction of foamed concrete, materials in foamed concrete, composition of foamed concrete, properties of foamed concrete, density of foamed concrete, advantages of using foamed concrete, foamed concrete applications, the effect of curing on the water permeability of foamed concrete and normal weight concrete, carbonation, effect of carbonation, rate of carbonation, water absorption, sustainable construction and lastly conclusion. Each sub-chapter written with critical discussion regarding the subject.

- The methodology of research is described in Chapter III. There are nine sub-chapters in it. The sub-chapters are introduction, methodology of study, foamed concrete mix design, equipment, preparation of materials, mixing of concrete, curing methods, testing and summary. Chapter III describes the methodology adopted in this research in order to produce best results comparable to other research findings and to follow the existing established standards.

- The analysis of data is presented in Chapter IV. This section compromise of eight sub-chapters which are introduction, water permeability, carbonation, compressive strength, water absorption, relationship between permeability coefficient, k and carbonation depth and also relationship between water permeability and carbonation depth. All the

CHAPTER II

LITERATURE REVIEW

2.0 INTRODUCTION

The density of normal weight concrete is about 2400 kg/m^3. Concrete with density lower than 2000 kg/m^3 is defined as lightweight concrete. According to Neville, A.M. (1995), the practical range of densities of lightweight concrete is between about 300 and 1850 kg/m^3. Clarke, J.L. (1993) defined that structural lightweight concrete as having an oven-dry density of less than 2000 kg/m^3. Foamed concrete is another type of lightweight concrete and is clearly described in the following section.

2.1 FOAMED CONCRETE

The history of foamed concrete began much later than lightweight aggregate concrete. According to Dubral, W. (1992), the development of the Autoclaved Aerated Concrete (AAC) began approximately 100 years ago. In 1914, the Swedes

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